



RESEARCH

FINAL REPORT

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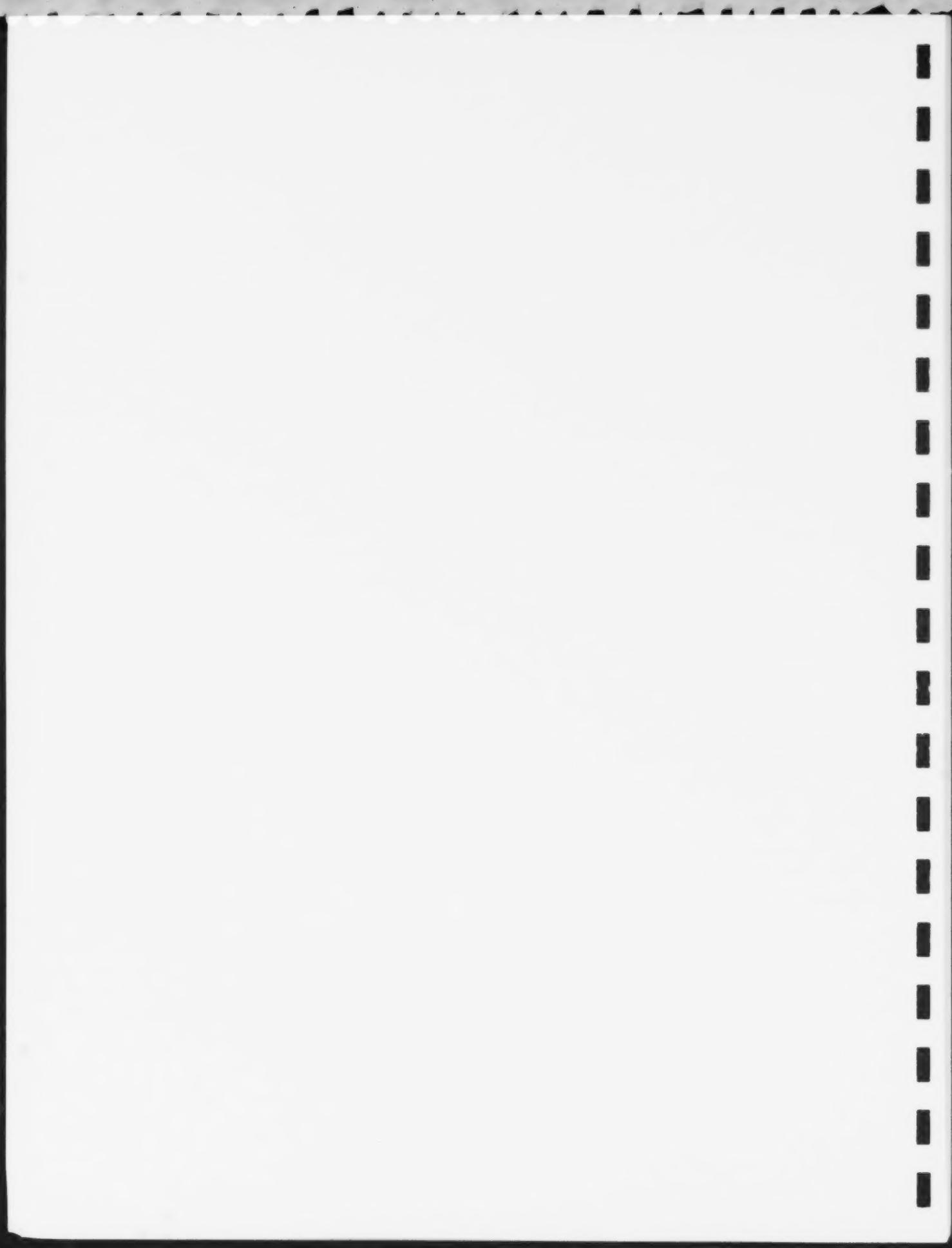
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SEEPAGE BENEATH CATTLE FEEDLOT PENS

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## Seepage Beneath Cattle Feedlot Pens

### Final Report Feb 2009

*ADF Project 2006-0128*



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**In Kind and Access:** Owner of the feedlot studied is recognized for access to feedlot and use of backhoe equipment.

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## Executive Summary

The general objective of this study was to determine the susceptibility of earthen floored feedlot pens to seepage of water and manure solutes. Specific objectives were: 1) to determine which parameters are suitable for indicating seepage; 2) to determine how much water and solute seepage occurs; 3) to determine the portion of seepage that occurs within the general soil matrix or as bypass flow along large continuous pores; and 4) to determine whether seepage is localized within pens.

One pen within a suitable feedlot was sampled within in the fall of 2007. Trenches were opened at three locations; under the mound, near the feed bunks, and at the lowest slope position within the pen. Observations and samples were taken to a depth of 2 m. The trenches were packed back to predisturbance compaction levels or better. Adjacent to each trench a tracer solution, consisting of potassium bromide and fluorescent dyes, was sprayed on the pen surface. In fall of 2008 soil samples were taken to determine the tracer presence at depth.

Soil analysis showed the site to have appreciable coarse fragment (> 2 mm) content (10 to 35%) and a low clay content (3 to 11%). Soluble soil chemistry indicates moderate salinity in the upper 0.30 m (~2.5 dS/m) of the feedlot decreasing to about 0.6 dS/m at 2.2 m depth. The lower part of the feedlot, had a lower surface EC at 1.5 dS/m. Some soluble ions,  $K^+$  and  $Na^+$ , were high in the upper meter relative to the 1-2 m depth. This, in conjunction with low concentrations of  $Ca^{2+}$  and  $Mg^{2+}$ , is indicative of manure solutes having seeped to at least 1.5 m depth. Seepage is estimated to be at least 18 mm/yr of water in the corner and 11 mm/yr under the feedlot pen. Movement of dissolved salts from the pen surface is estimated to be at 114 g/m<sup>2</sup> of pen floor per year. Tracers added in 2007 were not detectable in the 2008 samples. This could be due to the effects of dilution and runoff.

The potassium cation was to be the strongest single indicator for tracing manure seepage, however  $K^+$  will move slower than other ions or that of water due to its affinity for clays. The cations  $Ca^{2+}$ ,  $Mg^{2+}$ , and  $Na^+$  were also good indicators of manure movement if interpreted relative to each other. Electrical conductivity and  $Cl^-$  were not suitable here as they appeared to have moved deeper than the sampling depth (2.2 m). Other measured soil parameters;  $NO_3^-$ , Total N, Organic C, Total C did not display any trends that helped with analysis of manure seepage.

In summary the site investigated had a lower than expected clay content and thus a higher than expected seepage rate. Seepage within the feedlot pen area utilized by cattle was lower than a corner where runoff waters gathered.

## 1. Introduction

Statement and Relevance. Assessment of the potential for seepage beneath feedlots is important for reduction of groundwater contamination – if it occurs. Design of adequate feedlot pens such that seepage is slowed so that it will not reach groundwater resources is essential for sound feedlot management and economics. Seepage will depend upon a number of factors; permeability of the pen floor and the material underlying the pen floor, and pen management factors such as frequency of cleaning, pen scraping and depth of pen floor that is removed by scraping, pen slope, placement of pen mound, whether liquids pond within the pen, stocking density, and climate.

Purpose. The overall purpose of this study is to define the hydrology of prairie cattle feedlot pens with emphasis placed upon understanding solute and water seepage. The goal is to construct and validate a seepage model that incorporates regional climate and soils conditions that will aid feedlot design.

Objectives: The general objective is to determine the susceptibility of earthen floored feedlot pens to seepage of water and manure solutes. Seepage is defined as the amount of water and substances transported within water (e.g. dissolved ions, nutrients, organics) from the surface to the groundwater zone. Groundwater is the zone beyond the root zone (about 1 m in depth) and may be unsaturated or saturated. Specific objectives are related to field studies of feedlots:

- 1) to determine seepage indicators (e.g., moisture content, different N and P forms, anions and cations, electrical conductivity, dissolved organic carbon, bacteria);
- 2) to determine how much seepage occurs (e.g. mm of water per year, mass of solutes per  $m^2$  per year);
- 3) to determine the portion of seepage that occurs within the general soil matrix or as bypass flow along large continuous pores (e.g. cracks, old root channels, or other biopores); and
- 4) to determine whether seepage is localized within pens (e.g. within low lying areas or under straw-manure mounds).

With time and resources permitting a fifth objective may be undertaken; to determine the effect of scraping and pen inactivity upon seepage potential.

## 2. Literature Review

There is very little recent research upon seepage beneath feedlot pens and very few recent (1990's to present) published articles. There were a number of studies done in the 1970s within both Canada and the US. Some of this work pointed to increased movement of nitrates from inactive pens. Kennedy et al (1999) in a runoff study in Alberta, found the presence of chloride in the pen floors indicating that some seepage had occurred. Maule and Fonstad (1997, 2000, 2002) studied groundwater beneath pens and took soil cores beneath pens and found evidence of seepage in pen soil material but also that bypass flow from within or outside the pens was getting manure solutes into shallow groundwater. McMillan et al (2001) took cores through feedlots in Manitoba and found evidence of seepage in feedlots. McCullough et al (2001) looked at the infiltration characteristics of new pens and found that seepage might be higher at the initial stages of pen use.

## 3. Materials and Methods

The primary focus of the project is trenches excavated through an existing 27 year old feedlot pen to a depth of about 2 m. The trenches exposed a vertical profile along which samples were taken, for chemical analysis and observations of visible seepage indicators. In the first year of the study (fall 2007) three trenches were opened for sampling and observations. On adjacent parts of the pen a tracer (harmless to cattle) was placed in the feedlot floor. In the following year (fall 2008) another series of trenches were excavated and samples taken for tracer analysis.

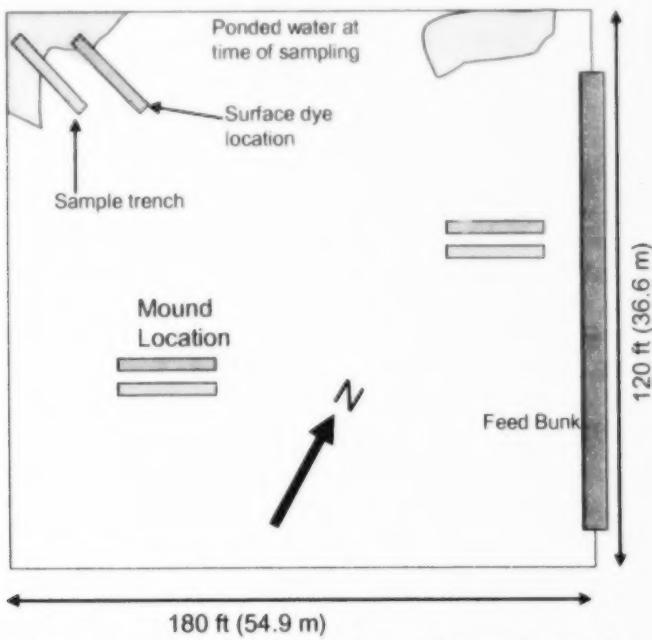
Due to expense the study was limited to only one feedlot. An appropriate feedlot was found and sampled by September 2007. The feedlot is located about 1.5 hours outside of Saskatoon. The pen studied was established in 1979 and has been in use continuously since then. Fig. 3.1 and Fig. 3.2 show the feedlot pen and trench locations. The pen was about 150 ft by 150 ft and had varied slopes ranging from 1 to about 5%.

The local landscape is gently sloping (2-5%) with slopes up to 5%. Naturally formed soils of the area are a mixture of Gray soils formed in loamy glacial till and Dark Gray soils formed in shallow, silty lacustrine materials underlain by glacial till (Saskatchewan Institute of Pedology, 1989). The majority of the landscape is Class 2 (30%) or Class 3 (70%) with major limitation is adverse soil structure and excess stoniness. Melfort is the nearest Environment Canada climate station (Melfort CDA 1971-2000) and has 309 mm of rain a year and 114 mm of snow per year. A 1 in 25 year 24 hour rain storm is 64 mm and a 1 in 25 year wet season (April to October) is 460 mm.

Three trenches were excavated in early September 2007 and September 2008 (Figs. 3.1 and 3.2). The trenches in 2008 were adjacent but not the same location of those of 2007. Each trench was excavated, with a backhoe, to about 2.2 m depth. The trenches were sloped along one side to reduce the possibility of slumping. One wall was left vertical for that of sampling. Disturbed samples were taken at approximately 0.30 m intervals from the surface to 2 m depth with the sample coming from the entire interval. Five profiles

were sampled in each trench. All samples were put into a cooler (5 to 10°C) and frozen by the end of the day until analysis could be done. Undisturbed cores (70 mm diameter by 100 mm length) were taken for bulk density and hydraulic conductivity measurements. Due to sample disturbance hydraulic conductivity measurements were not made.

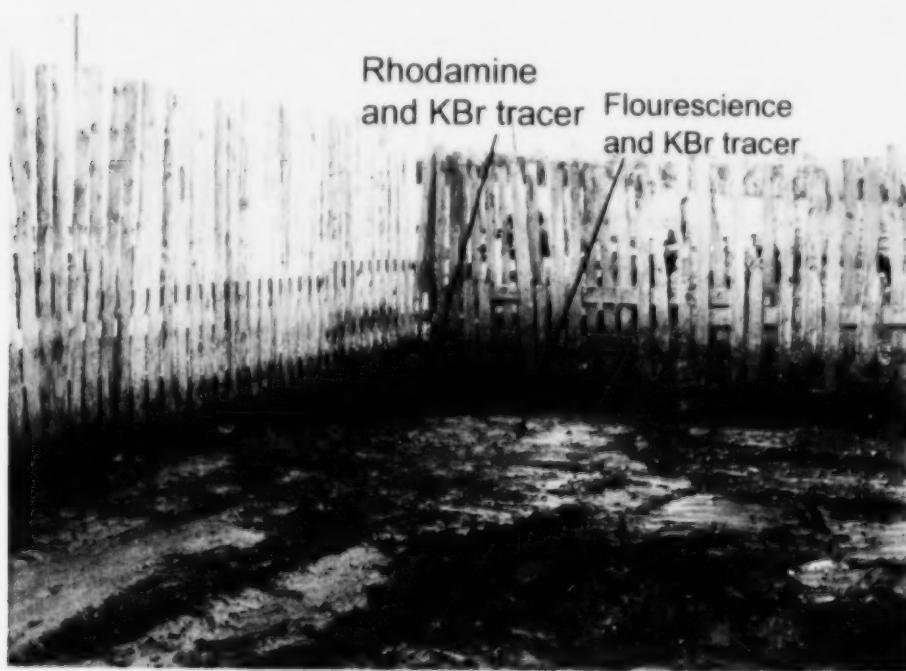
On a strip of the same pen, and adjacent to the 2007 sample trenches but not disturbed by sampling, a tracer was sprayed on the surface (Fig. 3.3). Two tracer solutions were mixed; one with Fluorescein (500 mg/L) and one of Rhodamine Red (500 mg/L). Both tracer solutions also had a second tracer, KBr at 500 mg/L. Fluorescein is a yellow visible dye that fluoresces with UV and is adsorbed less on soil surfaces than Rhodamine Red. The Rhodamine Red thus can show where water paths flowed in the soil (e.g. can highlight any cracks or channels). The tracers were sprayed on top of the scraped pen surface at an amount of approximately 2 liters per m<sup>2</sup> (1000 mg of tracer per m<sup>2</sup> of pen surface). The spray path was about 1 m wide and 3 m long. It was estimated that allowing for 50% runoff losses and mixing with soil water in the upper 0.30 m (volumetric moisture content at 0.20 m<sup>3</sup>/m<sup>3</sup>) that the soil concentration would be diluted to 8.3 mg/L, which is well above detection concentrations of 0.1 mg/L or less for these tracers. Presence of tracers in the excavated pit were checked visually and with a UV light that results in Fluorescein of both Fluorescein and Rhodamine red so that they can be visually detected at lower concentrations than with normal light.



**Fig. 3.1 Feedlot pen showing location of sample trenches and surface dye application.**



**Fig. 3.2. Photo of feedlot pen used for study.** Person in pen is at the approximate location of the feedlot mound. The bunk sample location is near the backhoe and the corner location is that behind the person.



**Fig. 3.3. Pen surface in corner site of feedlot showing spray patterns of dyes.**

Samples obtained from 2007 and 2008 sampling were analyzed for some physical properties, soluble chemistry and total C, N, and S (Table 3.1). The grain size distribution was determined from selected samples using the Laser Scattering Particle Size Distribution Analyzer (Horiba LA-950). Porosity was calculated from dry bulk density assuming a particle density of 2650 kg m<sup>-3</sup>.

All chemical analysis were performed on 2:1 (approximate volume basis) extracts prepared from core samples that had been air-dried, ground, and sieved to less than 2 mm. Analysis of grain size distribution, total and organic carbon, cations (Na, K, Ca, and Mg), dissolved ions (Cl, SO<sub>4</sub>, and NO<sub>3</sub>), total C, N, S, and P, and Fluorescein were done in Soil Science Department's laboratories, University of Saskatchewan. Total C, N, and S were measured using CNS (Leco-2000) analyzer. Dissolved ions Cl, SO<sub>4</sub>, and NO<sub>3</sub>, and total N and P were measured using "Technicon" Auto-analyzer. Nitrate and sulfate were measured according to the method described by Clesceri et al. (1998) and Wall et al. (1980), respectively. Soil samples were digested in a sulfuric acid digestion for total N and P measurements as it was described by Lindner and Harley (1942). Atomic Absorption Spectrometer (Apectr AA 220) was used for measuring Ca, Mg, K, and Na. Fluorescein was measured using Spectrophotometer (UV-VIS 1240) with wave length of 450 nm. Carbon Analyzer (Leco C632) was used for measuring organic and total carbon in the soil samples. Electrical conductivity (EC) was measured in Agricultural and Bioresource Engineering Department's laboratory, University of Saskatchewan, using pH/ISE meter (ORION 290A). ALS laboratories were responsible for bromide measurements. Rhodamine red was measured in Civil and Geological Engineering's laboratory, University of Saskatchewan, using a Fluorometer (Turner Designs 10-AU) with an excitation wave length of 546 nm as it described by Turner Designs (2009).

**Table 3.1. Laboratory analysis**

Property	2007	2008
grain size	3P, 1S, 7D	
bulk density	NA	3P, 3S, 3D
Moisture content (kg/kg)	3P, 5S, 7D	
total carbon	3P, 5S, 7D	
Inorganic & organic carbon	3P, 5S, 7D	
EC	3P, 5S, 7D	3P, 5S, 6D
SO <sub>4</sub>	3P, 5S, 7D	
NO <sub>3</sub>	3P, 5S, 7D	3P, 5S, 6D
Cl	3P, 5S, 7D	3P, 5S, 6D
TN	3P, 5S, 7D	
TS	3P, 5S, 7D	
TC	3P, 5S, 7D	
TP	3P, 5S, 7D	
Ca	3P, 5S, 7D	
Mg	3P, 5S, 7D	
Na	3P, 5S, 7D	
Br	1P, 1S, 7D	3P, 1S, 6D
K	3P, 5S, 7D	
Rhodamine red	1P, 1S, 6D	3P, 5S, 6D
Fluorescein	1P, 1S, 6D	3P, 5S, 6D

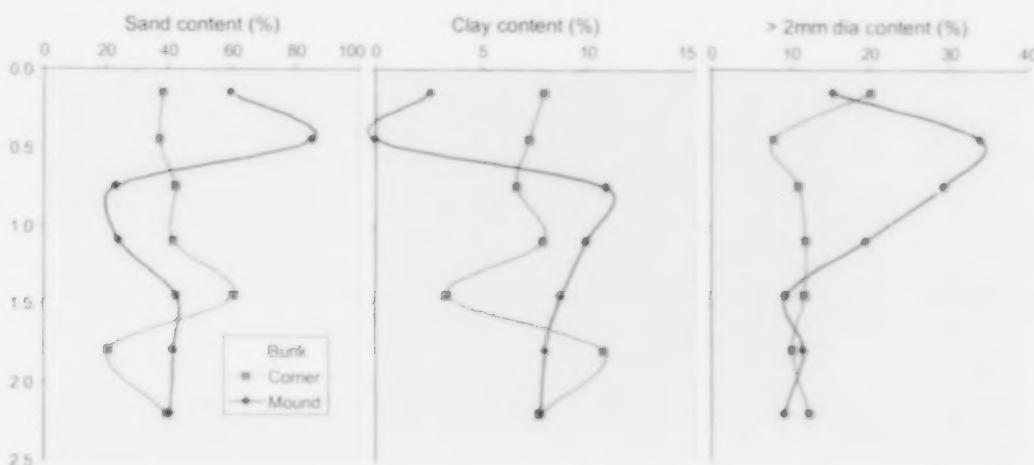
3P: 3 soil pits, 5S: 5 sites within each pit, 7D, 7 depths for each site, thus for these lab analysis there was a total of 75 samples analyzed (3x5x7)

## 4. Results

### 4.1. Soil Physical and visual conditions

Both pen sampling periods (2007 and 2008) took place in September after pen cleaning. Pen cleaning removed the hay/manure mound as well as accumulated manure in the pen such that most of the soil surface was exposed. Cattle stocking rate was at about 50 head.

The soils had appreciable coarse fragment ( $> 2\text{ mm dia.}$ ) content (22% by mass, with a standard deviation of 18%). The portion less than 2 mm diameter had low clay content ( $6\% \pm 3\%$  standard deviation) and high sand ( $48\% \pm 16\%$ ) and silt contents ( $47\% \pm 13\%$ ). The texture under the mound was appreciably different that that of the corner and near the bunk, with lower clay content and higher sand content in the upper 0.50 m but greater clay content to 1.5 m. (Fig. 4.1).



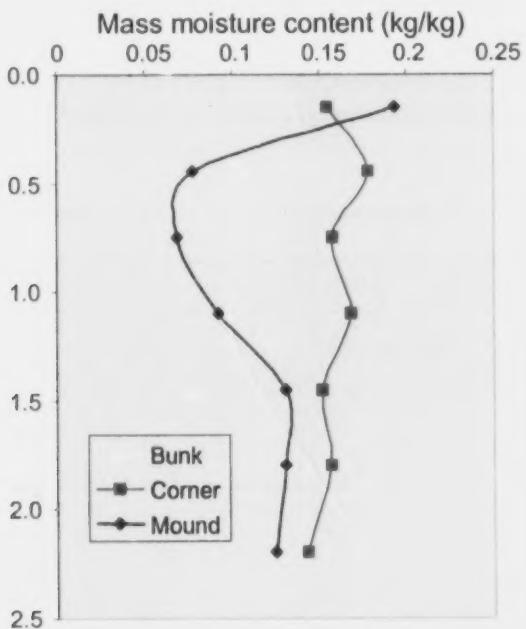
**Fig. 4.1. Sand, Clay, and Coarse Fragment ( $> 2\text{ mm}$ ) content.** Sand and clay contents are proportion of mass after removal of coarse fragments. Each data point is of one sample only.

As the facility was built on land cleared of forest there were a large volume of roots and organic material found in the upper 0.5 m. Gravel is found in various layers, to depths of about 1 m, and with unidentified organic material in the voids. Iron staining and salt crystals in fractures occurred at most locations at most depths. All of the samples were from oxidized material.

Bulk densities, as measured at 0.60, 1.00, and 1.60 m averaged  $1620\text{ kg m}^{-3}$  ( $\pm 86\text{ kg m}^{-3}$ ),  $1780\text{ kg m}^{-3}$  ( $\pm 87\text{ kg m}^{-3}$ ), and  $1820\text{ kg m}^{-3}$  ( $\pm 86\text{ kg m}^{-3}$ ) respectively. It is assumed that as there is no topsoil present within the feedlot, and that cattle do compact the surface material that the bulk density of the surface (0-0.30 m) will be at least  $1620\text{ kg m}^{-3}$ .

#### 4.2 Soil moisture

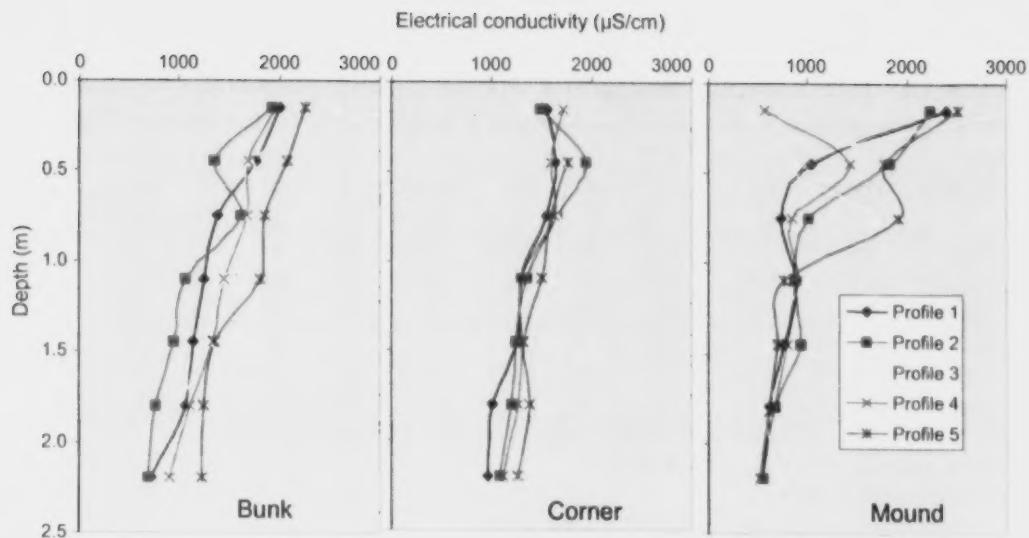
Soil moisture content was greatest under the low corner and least under the mound (Fig 4.2) especially between 0.20 m and 1.0 m depths. The presence of gravel and sand layers resulted in some variation of moisture content, however it is noted that the mound had the lowest clay content and highest gravel content (Fig. 4.1). There is an approximate inverse relationship between coarse fragment content and moisture content (Fig 4.1 and Fig. 4.2); the greater the coarse fragment content the lower the moisture.



**Fig. 4.2. Mass moisture content.** Each point is the average of 5 measurements with exception of low corner at 0.15 m and mound at 2.0 m which is from 4 measurements.

#### 4.3 Background Soil Chemistry

Soluble soil chemistry was determined from samples of all three pits at this pen. Within each pit 5 profiles were taken. Overall this chemistry can be represented by the electrical conductivity of the solutions (Fig 4.3 and Table 4.1) which provides an indication of the total dissolved concentration of ions. Generally the highest values are within the near surface (0.15 and 0.45 m), decreasing approximately linearly with depth. The mound has some of the highest near surface values (2000 to more than 3000  $\mu\text{S}/\text{cm}$ ) however also has the greatest range of values in the upper 0.75 m and the lowest values at 2.2 m depth (average of 601  $\mu\text{S}/\text{cm}$  as compared to 1207  $\mu\text{S}/\text{cm}$  and 1143  $\mu\text{S}/\text{cm}$  for the bunk and corner respectively). The corner has the lowest near surface values, but the highest values at depth.



**Fig. 4.3. Electrical conductivity of soil profiles within each of the sampling pits.** Each point is representative of one sample.

**Table 4.1. Soluble soil chemistry of selected depths.** Each value is the average of 5 samples.

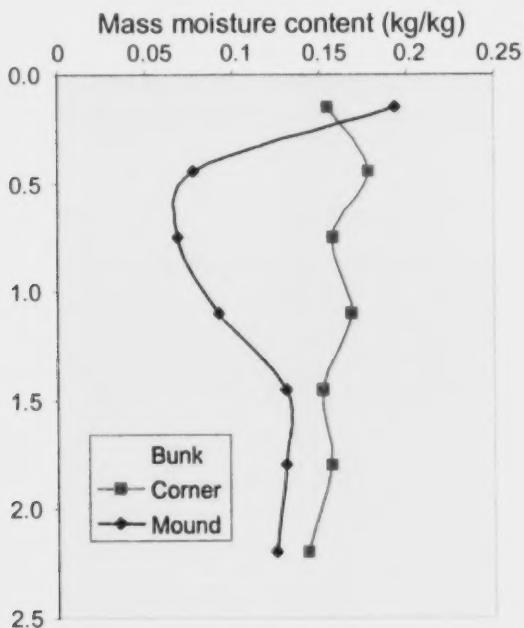
location	Depth m	EC µS/cm	Na <sup>+</sup> mg/L	Ca <sup>2+</sup>	Mg <sup>2+</sup>	SAR	K <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>
bunk	0-0.3	2154	77.7	17.1	10.8	3.58	558.4	279.0	44.2	0.85
corner	0-0.3	1539	39.2	17.5	5.1	2.12	413.4	128.8	36.0	2.17
mound	0-0.3	2150	65.6	26.0	16.2	2.62	483.0	232.5	40.1	1.03
bunk	1.6-2.0	1075	18.6	74.8	36.1	0.43	25.7	145.3	3.3	0.19
corner	1.6-2.0	1242	63.3	86.7	44.6	1.39	9.8	114.3	1.8	0.14
mound	1.6-2.0	629	5.9	55.8	15.0	0.20	8.6	85.2	1.8	0.44

The soluble ions of K<sup>+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, and NO<sub>3</sub><sup>-</sup> are all higher within the top 0.9 m of the soil than that at depth (Table 4.1, Fig. A.1 and A.2). Calcium and Mg<sup>2+</sup> increase with depth (Fig. A.1), whereas K<sup>+</sup> and Na<sup>+</sup> increase with depth (except for the corner profile which has a Na<sup>+</sup> bulge at about 1 m depth). The greatest cation values in the surface is that of potassium, and this has the greatest decrease with depth of all ions. The three anions measured (Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, and NO<sub>3</sub><sup>-</sup>) all have higher values in the surface soils than at depth (below 1 m). Chloride shows the least decrease with depth with that of the corner being very similar between the surface 0.3 m and that at depth (1.6-2.0 m). Nitrate and SO<sub>4</sub><sup>2-</sup> are high within the top 0.3 m and decrease sharply.

Some soil chemistry (total N and C) and physical properties are presented in Table 4.2. As with much of the soluble chemistry TN and organic carbon (orgC) in the surficial materials was highest in the bunk and mound locations, but at depth only the bunk was higher.

#### 4.2 Soil moisture

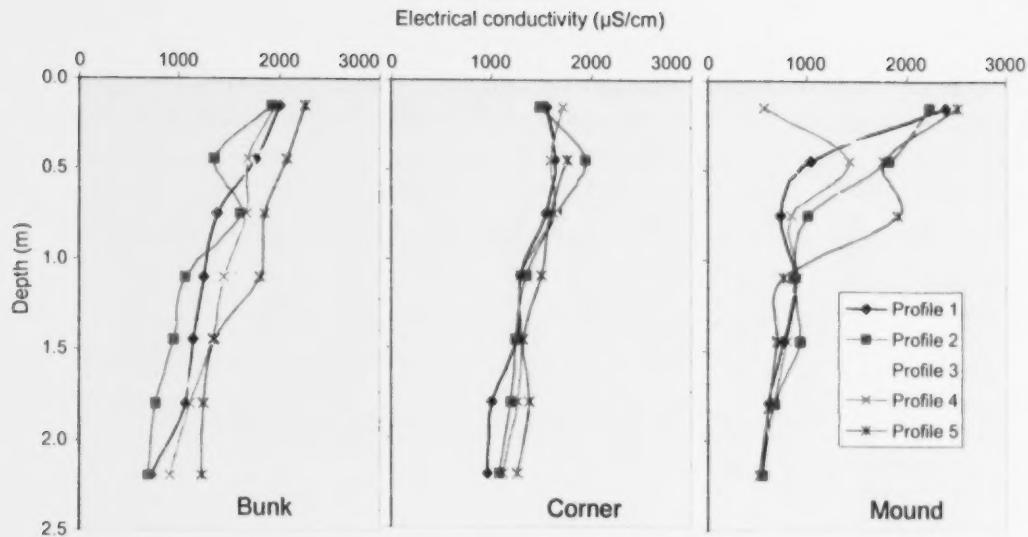
Soil moisture content was greatest under the low corner and least under the mound (Fig 4.2) especially between 0.20 m and 1.0 m depths. The presence of gravel and sand layers resulted in some variation of moisture content, however it is noted that the mound had the lowest clay content and highest gravel content (Fig. 4.1). There is an approximate inverse relationship between coarse fragment content and moisture content (Fig 4.1 and Fig. 4.2); the greater the coarse fragment content the lower the moisture.



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Each point is representative of one sample.

**Table 4.1. Soluble soil chemistry of selected depths.** Each value is the average of 5 samples.

location	Depth m	EC µS/cm	Na <sup>+</sup> mg/L	Ca <sup>2+</sup>	Mg <sup>2+</sup>	SAR	K <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>
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Some soil chemistry (total N and C) and physical properties are presented in Table 4.2. As with much of the soluble chemistry TN and organic carbon (orgC) in the surficial materials was highest in the bunk and mound locations, but at depth only the bunk was higher.

**Table 4.2. Total nitrogen, total carbon, and soil physical properties** (Nitrogen, carbon, and particle size values are average of 2 samples. Moisture content is average of 5).

location	Depth m	TN %	TC %	orgC %	iC %	>2mm %	S %	Si %	C %	mc
bunk	0-0.3	0.16	2.48	1.80	0.68	34	60	36	4	14
corner	0-0.3	0.08	3.40	1.05	2.35	20	38	54	8	15
mound	0-0.3	0.20	2.51	2.33	0.18	15	60	38	3	19
bunk	1.6-2.0	0.12	0.88	0.73	0.14	10	32	60	8	14
corner	1.6-2.0	0.04	2.72	0.52	2.20	10	21	69	11	16
mound	1.6-2.0	0.04	2.75	0.49	2.25	12	42	50	8	13

TN: total nitrogen. TC: total carbon. orgC: organic carbon. iC: inorganic carbon

>2mm: particles with diameter > 2 mm

S: sand. Si: silt. C: clay

mc: mass moisture content (kg water/kg of dry soil)

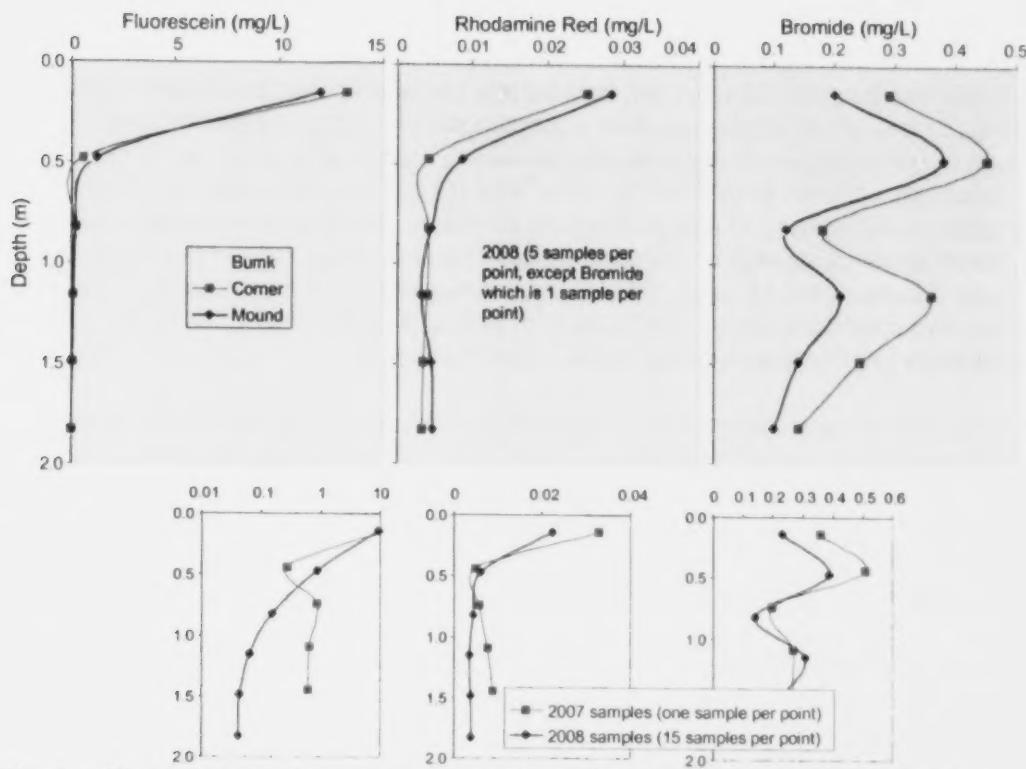
#### 4.4 Chemistry after tracer addition

Three tracers had been added to the feedlot surface in the fall of 2007, after sampling; Fluorescein, Rhodamine Red and Bromide (Fig. 4.4). The tracer concentration when added was approximately 500 mg/L and 2 liters per m<sup>2</sup> was added. All of the recovered values are very low, although surface samples (0.15 m) are higher than deeper depths for Fluorescence and Rhodamine Red. The higher values at 0.15 m are likely related to the interference of organics as the same trend appeared in the 2007 samples even though these tracers were not present.

Because of the dilution effect of the 2:1 (water:soil by volume) water extraction method and the approximate 0.20 m<sup>3</sup>/m<sup>3</sup> background moisture content the actual concentration of these tracers, in the soil, would be about 10 times greater than that shown in Fig. 4.4.

Bromide in 2008 did not have higher values in the surface than at depth (Fig. 4.4), although all 3 locations agreed in trend with two peaks at about 0.45 m and at 1.1 m. However the values are not different from the set of 2007 samples (which had no bromide added).

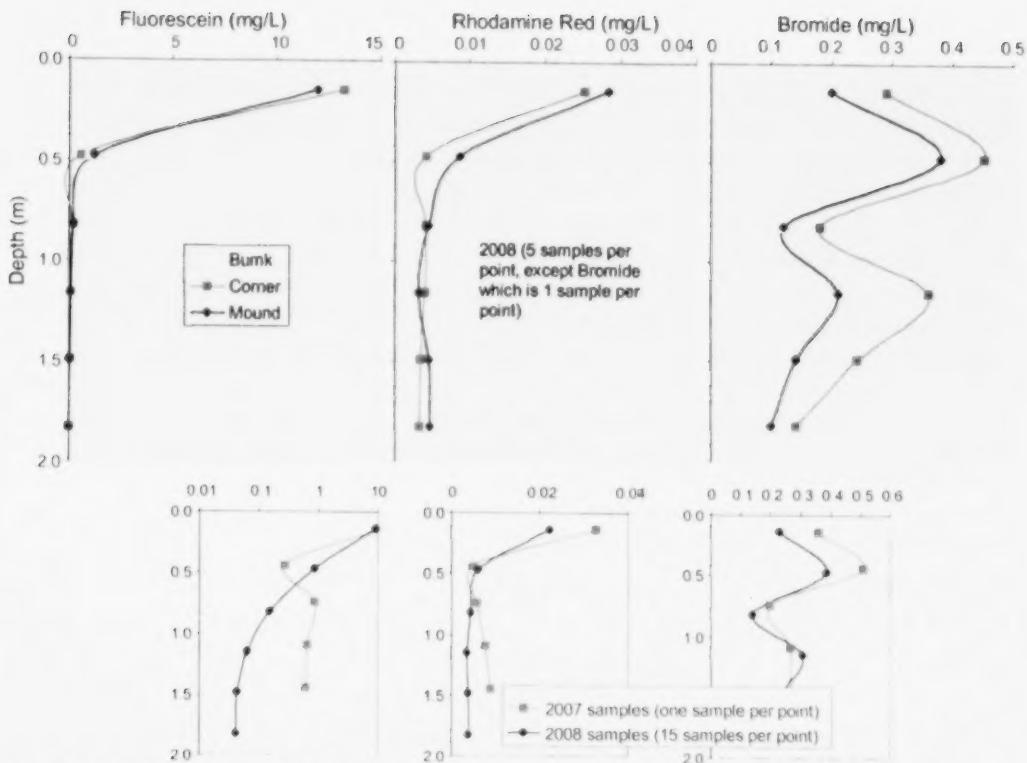
Thus based upon the low concentrations and the similar concentrations from 2007 samples, taken from before the tracers were added, the conclusion is there is no indication of seepage during the period of one year.



**Fig. 4.4. Distribution of tracers concentrations with depth one year after addition (2008).** As part of control one set of samples from 2007 were analyzed even though no tracer had been added.

## 5 Seepage Analysis

Seepage analysis includes that of the background soil chemistry and those added as a tracer (Flourescence, Rhodamine Red, and Br<sup>-</sup>). Manure is generally higher in potassium and sodium than in Ca<sup>2+</sup> and Mg<sup>2+</sup> (Maule and Fonstad, 1997), whereas prairie tills and soil materials are generally higher in Ca<sup>2+</sup> and Mg<sup>2+</sup> than Na<sup>+</sup> and K<sup>+</sup> in solution and on exchange sites. The trend of increasing Ca<sup>2+</sup> and Mg<sup>2+</sup> with depth and decreasing K<sup>+</sup> and Na<sup>+</sup> with depth is likely due to downward movement by the manure solutes K<sup>+</sup> and Na<sup>+</sup>, replacing that of Ca<sup>2+</sup> and Mg<sup>2+</sup> on the exchange sites. If so then the depth of manure solute penetration could be about 1.5 m. Cations normally do not travel as fast as the flow rate of water as cations are retarded in flow due to their exchange with clay exchange sites, however the clay content is low at this site. Chloride, being an anion, is not affected by the clay cation exchange sites and thus can travel with water flow. Normal soluble chloride content of soils is much less than 100 mg/L (Maule and Fonstad, 1997) and the chloride in these pens is from from feedlot manure. Using chloride as a manure tracer, seepage could be greater than 2 m depth.



**Fig. 4.4. Distribution of tracers concentrations with depth one year after addition (2008).** As part of control one set of samples from 2007 were analyzed even though no tracer had been added.

## 5 Seepage Analysis

Seepage analysis includes that of the background soil chemistry and those added as a tracer (Flourescence, Rhodamine Red, and Br<sup>-</sup>). Manure is generally higher in potassium and sodium than in Ca<sup>2+</sup> and Mg<sup>2+</sup> (Maule and Fonstad, 1997), whereas prairie tills and soil materials are generally higher in Ca<sup>2+</sup> and Mg<sup>2+</sup> than Na<sup>+</sup> and K<sup>+</sup> in solution and on exchange sites. The trend of increasing Ca<sup>2+</sup> and Mg<sup>2+</sup> with depth and decreasing K<sup>+</sup> and Na<sup>+</sup> with depth is likely due to downward movement by the manure solutes K<sup>+</sup> and Na<sup>+</sup>, replacing that of Ca<sup>2+</sup> and Mg<sup>2+</sup> on the exchange sites. If so then the depth of manure solute penetration could be about 1.5 m. Cations normally do not travel as fast as the flow rate of water as cations are retarded in flow due to their exchange with clay exchange sites, however the clay content is low at this site. Chloride, being an anion, is not affected by the clay cation exchange sites and thus can travel with water flow. Normal soluble chloride content of soils is much less than 100 mg/L (Maule and Fonstad, 1997) and the chloride in these pens is from from feedlot manure. Using chloride as a manure tracer, seepage could be greater than 2 m depth.

Cation concentration at depth ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ , and  $\text{Na}^+$ ) as well as EC is lowest under the mound. There could be the possibility that the pen is drier under the mound and thus the downward flow rate of water is less.

Given that the pen is 27 years old, then the rate of manure solute movement would be at least 55 mm of soil depth/year (from a cation depth of 1.5 m), and possibly more than 81 mm of soil depth/year (using chloride penetration depth to at least 2.2 m). If the volumetric moisture content is  $0.20 \text{ m}^3/\text{m}^3$  then the moisture movement to obtain these depths would be from 11 mm/yr to at least 16 mm/yr. For normal agricultural soils this would not be unreasonable. Previous studies have shown that manure flux beneath pens to be between 2 and 18 mm/yr (Maule and Fonstad 1997). Of note is that  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  have lower concentrations in the upper 0.90 m than at depth. This could be by replacement of the cation by  $\text{Na}^+$  and  $\text{K}^+$  from the manure.

If the manure contribution to EC at the surface of the pen (except for the low corner) is  $2150 \mu\text{S}/\text{cm}$  and the soil background is  $600 \mu\text{S}/\text{cm}$  (2.2 m depth at the mound) and annual moisture flow is 11 mm/yr then the annual total dissolved solids contribution from manure could be  $114 \text{ g m}^{-2} \text{ yr}^{-1}$  of pen floor (assuming that the measured EC values are 10 times diluted from soil pore water and that EC can be converted to mg/L by multiplying by 0.67; Watling, 2007).

For the tracers, the reported amounts (Fig. 4.4) are approximately 10 times lower than that which would occur in soil water. Thus a measured  $\text{Br}^-$  concentration of 0.2 mg/L would be about 2.0 mg/L within the soil solution. This concentration is approximately what would occur given the following:

Moisture content of upper 0.30 m of soil:  $0.20 \text{ m}^3/\text{m}^3$

Concentration of tracer when applied: 500 mg/L

Amount of tracer applied: 2 L/m<sup>2</sup>

Assumed depth of penetration of tracer: 0.30 m

Thus if half the tracer stayed within the soil (the other half leaving the pen in runoff), then the concentration of tracer within the upper 0.30 m of soil should be 8.3 mg/L of soil solution (at  $0.20 \text{ m}^3/\text{m}^3$ ) and would decrease for increasing runoff (Table 4.3).

**Table 4.3. Assumed concentration of tracer in soil water and sample water (mg/L).**

Tracer retained ratio	Tracer in soil mg/L	Tracer in sample mg/L
0.1	1.7	0.17
0.3	5.0	0.50
0.5	8.3	0.83
0.7	11.7	1.17
0.9	15.0	1.50
1.0	16.7	1.67

Values are calculated based upon an applied tracer concentration of 500 g/L, 2 L applied per m<sup>2</sup> of soil surface, an assumed volumetric moisture content of  $0.20 \text{ m}^3/\text{m}^3$  and complete mixing of the tracer in the upper 0.30 m of soil.

Tracer retained is the proportion of tracer not lost by runoff, absorption or decomposition.

From Table 4.3 it thus appears that the tracer retained in the upper 0.30 m of soil was less than 10% of that applied. It thus appears that much of the tracer (more than 90%) was not retained within the soil and could have been removed by runoff or distributed to greater depths. A higher concentration and a longer time period of observation is thus required.

## 6. Conclusions and Recommendations

With regards to the objectives the following conclusions may be made in context of the site studied:

Objective 1. Determination of seepage indicators: The following soil ions proved useful as an indicator of manure seepage either by itself or in use with other soil parameters;  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ , and  $\text{K}^+$ . Potassium, being high in manure, low in natural soils, and more resistant to transport than the other cations had the most distinctive plume. Calcium and Magnesium appeared to have been depleted in the upper meter (likely being replaced by  $\text{K}^+$  and  $\text{Na}^+$ ) and higher in the bottom meter. Normally movement of soluble cations is retarded with clay exchange sites, however texture at this site was low in clay content.

Other properties, such as EC and  $\text{Cl}^-$ , were limited in their ability to indicate seepage as their plumes were not as distinct. This could be due to the depth of seepage having passed the depth of sampling (2.2 m).

Some other properties such as  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ , total nitrogen, and organic carbon, may be of use however the ability to provide interpretation to their distribution at this site was limited.

Other properties, such as moisture content and total carbon appeared to have neither indication nor potential for being seepage indicators.

Objective 2. Determination how much seepage occurs: at this site it appears that at least 11 mm of water per year seeps through the profile with more occurring in a low lying part of the pen. These could be bringing with it 114 g of dissolved manure salts / $\text{m}^2$  of pen surface per year.

Objective 3. Determination of the portion of seepage that occurs in the general soil matrix or as bypass flow; this could not be quantified. There was insufficient dye tracer and any other indicators to make this possible

Objective 4. Determination of whether seepage is localized. There is some indication that seepage was greatest under low lying areas that collected runoff water and least under the mound area.

Objective 5. Determination of the effect of scraping. There was insufficient opportunity to investigate this option.

The following recommendations is for a more comprehensive study;

- Use a site with a higher clay content (15-25%);
- If tracers are used then at least 3 years of application and observation are needed;
- Tracers should be higher in concentration and/or higher application rate to account for amounts lost in runoff;

- Tracer fate, as lost in runoff should be monitored through collection of runoff and ponded water several times throughout the year.
- Feedlots older than 20 years should be sampled deeper than 2.2 m. Coring will be necessary for this.
- Visual observation proved to be very limited, if to be further pursued other color dye or tracer methods need to be investigated.

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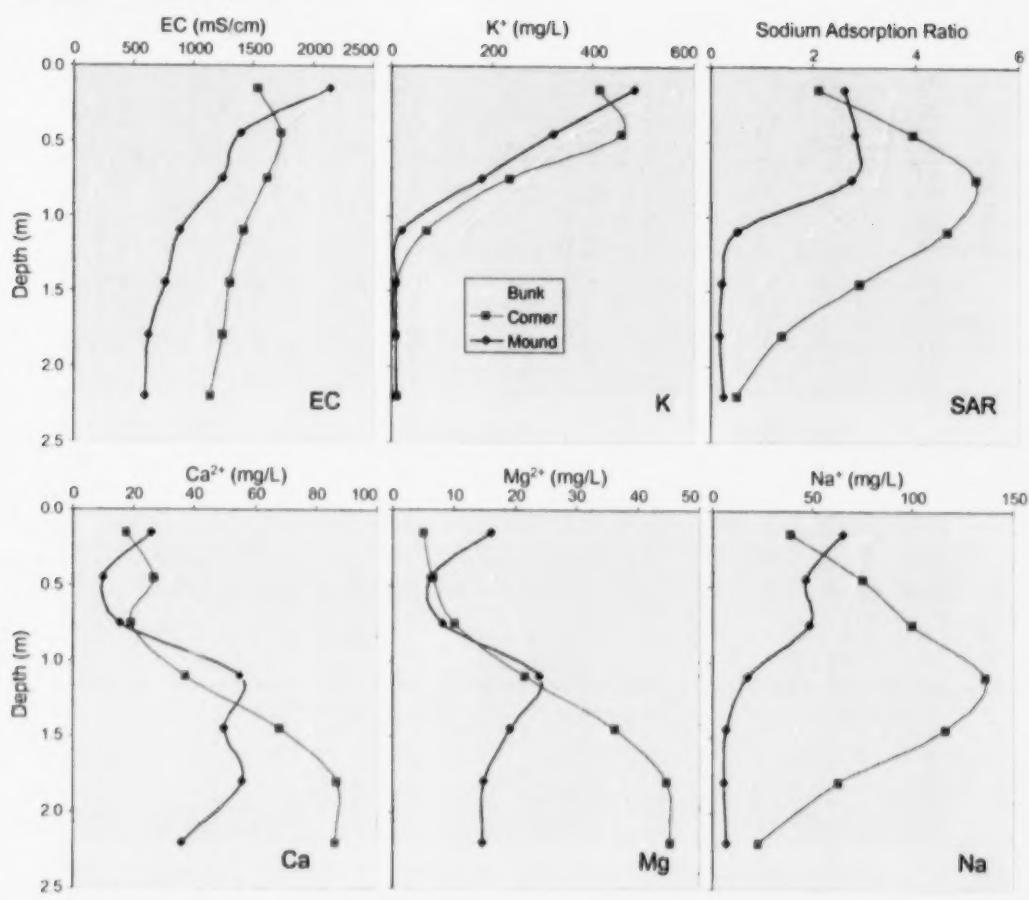
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## Appendix A: Data

### A1. Soil chemical profiles



**Fig. A.1. Soluble chemistry of K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup> and that of electrical conductivity (EC) and Sodium Adsorption Ratio (SAR). Each point is the average of 5 samples.**

## Appendix A: Data

### A1. Soil chemical profiles

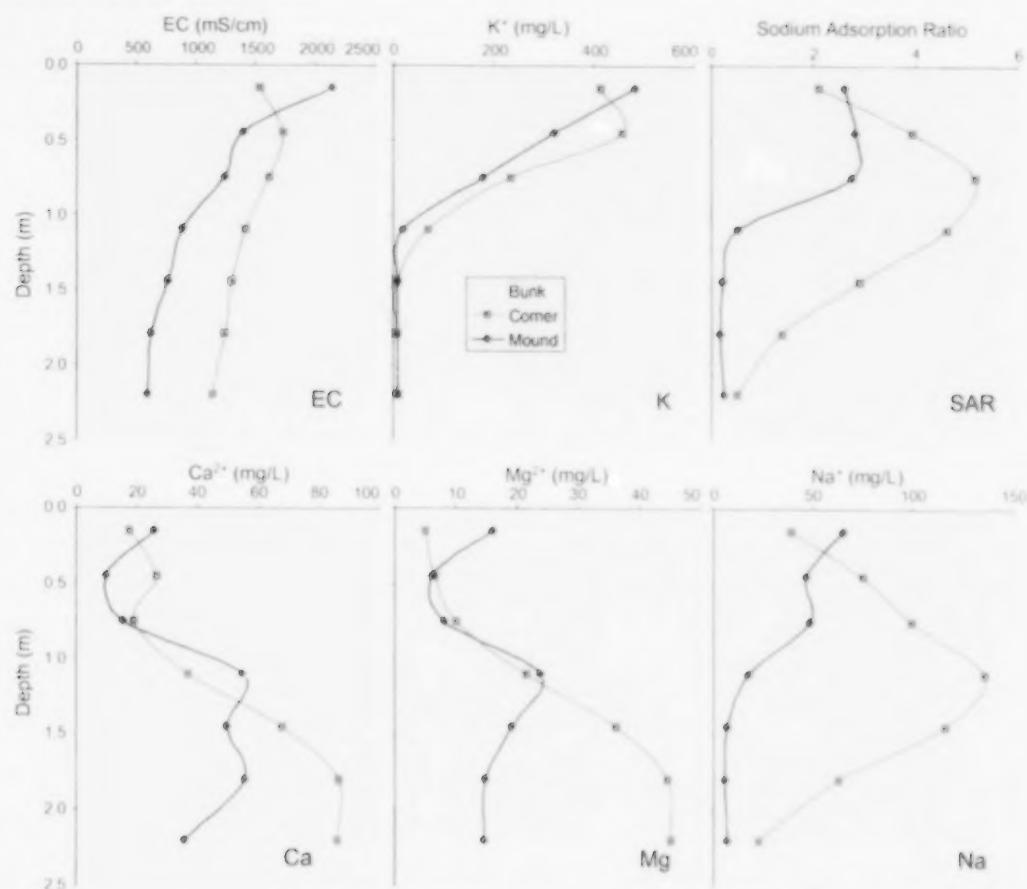
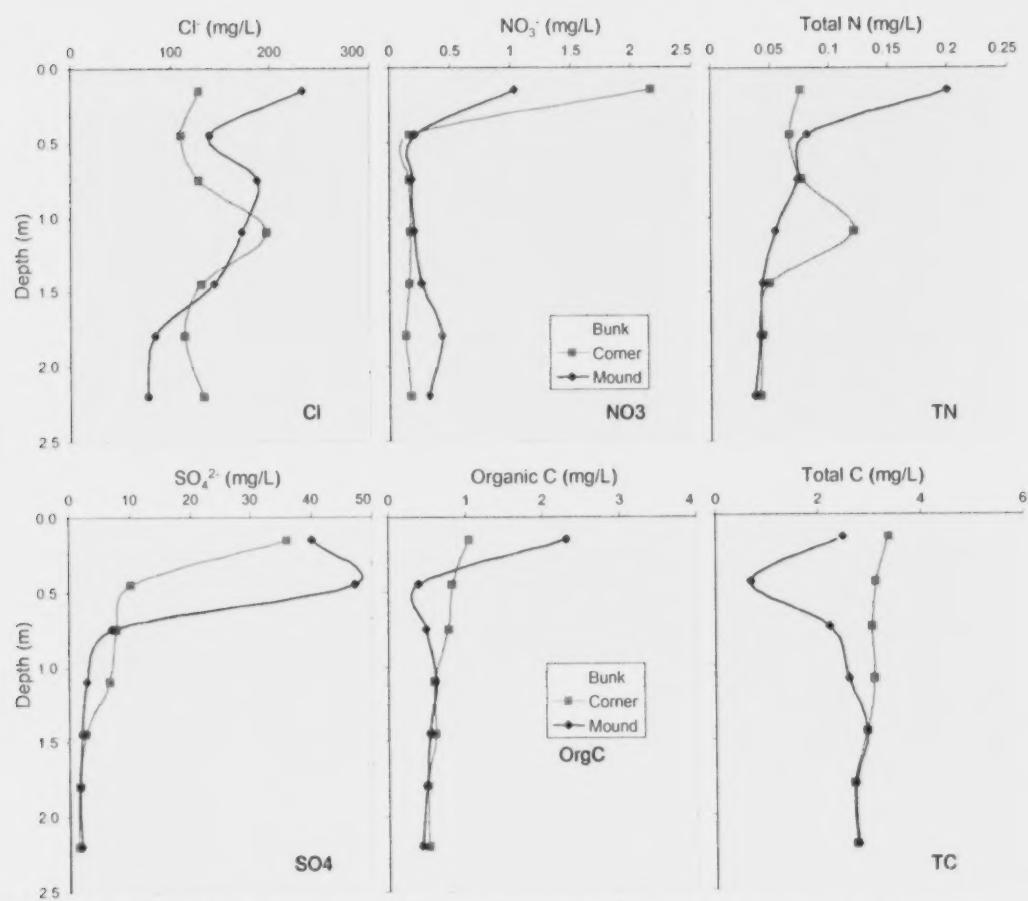


Fig. A.1. Soluble chemistry of  $K^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Na^+$  and that of electrical conductivity (EC) and Sodium Adsorption Ratio (SAR). Each point is the average of 5 samples.



**Fig. A.2. Soluble soil chemistry ( $\text{Cl}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$ , 5 samples per point) and total nitrogen, total carbon and organic carbon (2 samples per point)**

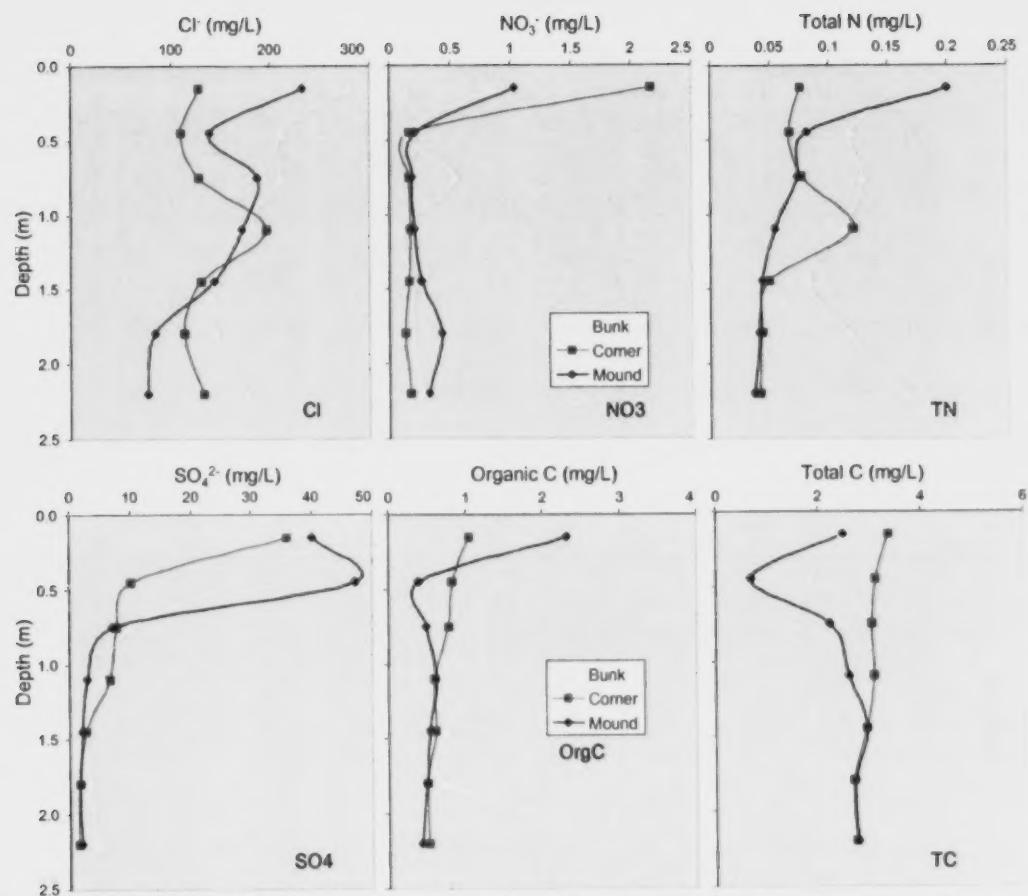


Fig. A.2. Soluble soil chemistry (Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup>, 5 samples per point) and total nitrogen, total carbon and organic carbon (2 samples per point)

## A2. Soil chemical data

**Table A-1. Soluble chemistry at bunk location**

location	ID#	Depth m	EC uS/cm	Ca mg/L	Mg mg/L	Na mg/L	SAR ratio	K mg/L	SO4 mg/L	Cl mg/L	NO3 mg/L
bunk	A1-1	0.15	2012	10.2	2.0	47.1	3.5	518.7	6.2	211.3	0.04
bunk	B1-1	0.45	1768	22.3	12.2	89.6	3.8	333.3	41.2	326.3	0.12
bunk	C1-1	0.75	1391	39.2	19.8	61.3	2.0	104.3	3.4	252.7	0.15
bunk	D1-1	1.1	1255	94.8	42.5	38.5	0.8	26.3	2.7	178.5	0.15
bunk	E1-1	1.45	1146	92.2	40.2	30.6	0.7	15.5	2.4	129.0	0.22
bunk	F2-1	1.8	1066	76.1	34.1	15.7	0.4	25.2	2.2	160.0	0.19
bunk	G2-1	2.2	718	34.5	19.2	8.5	0.3	19.8	1.9	73.2	0.22
bunk	A4-1	0.15	1928	11.3	2.7	31.7	2.2	525.8	15.8	345.9	0.07
bunk	B4-1	0.45	1350	94.4	47.8	35.9	0.7	27.8	1.8	276.4	0.10
bunk	C4-1	0.75	1613	152.3	68.2	26.7	0.5	27.8	3.3	248.3	0.16
bunk	D4-1	1.1	1071	78.5	35.0	13.7	0.3	17.7	4.2	166.4	0.11
bunk	E4-1	1.45	947	48.4	25.9	15.5	0.4	43.9	3.1	128.3	0.21
bunk	F4-1	1.8	771	43.6	25.6	8.1	0.2	19.8	7.4	77.4	0.22
bunk	G4-1	2.2	697	46.3	21.6	7.5	0.2	20.1	3.8	62.9	0.37
bunk	A6-1	0.15	2607	24.6	23.4	126.9	4.4	687.5	54.0	286.8	0.05
bunk	B6-1	0.45	1719	11.1	6.2	71.1	4.2	457.4	23.8	116.8	0.06
bunk	C6-1	0.75	1709	13.5	4.1	81.0	4.9	420.3	13.7	149.7	0.06
bunk	D6-1	1.1	1485	42.6	12.1	85.2	3.0	226.1	10.3	113.3	0.04
bunk	E6-1	1.45	1307	108.5	44.6	57.9	1.2	35.6	1.8	160.6	0.20
bunk	F6-1	1.8	1177	77.1	38.5	24.2	0.6	30.0	2.5	169.6	0.21
bunk	G6-1	2.2	2485	222.7	104.3	61.8	0.9	22.2	2.7	474.2	0.19
bunk	A9-1	0.15	1959	19.3	10.0	85.6	3.9	467.7	23.2	197.9	4.03
bunk	B8-1	0.45	1686	11.6	6.5	72.8	4.2	442.7	49.9	150.5	0.11
bunk	C8-1	0.75	1666	12.4	4.7	74.2	4.5	382.8	12.7	131.7	2.16
bunk	D8-1	1.1	1446	14.6	5.7	63.1	3.5	230.4	4.8	224.4	0.14
bunk	E8-1	1.45	1340	52.3	21.6	65.5	1.9	96.3	5.2	148.4	0.17
bunk	F8-1	1.8	1118	85.1	36.1	20.1	0.5	25.6	2.8	113.5	0.18
bunk	G8-1	2.2	902	63.9	24.5	19.1	0.5	43.1	4.3	89.9	0.40
bunk	A9-1	0.15	2264	20.3	15.9	97.0	3.9	592.2	121.9	352.9	0.07
bunk	B9-1	0.45	2081	24.5	7.7	89.8	4.0	532.1	19.3	180.7	0.35
bunk	C9-1	0.75	1860	13.1	6.4	75.4	4.3	389.9	17.5	272.0	0.19
bunk	D9-1	1.1	1814	50.5	24.9	74.7	2.1	202.1	5.0	152.5	0.13
bunk	E9-1	1.45	1352	93.2	43.2	42.7	0.9	34.9	2.1	161.0	0.18
bunk	F9-1	1.8	1244	92.3	46.5	24.6	0.5	27.7	1.7	206.0	0.16
bunk	G9-1	2.2	1232	76.9	36.3	28.2	0.7	87.6	10.3	181.7	0.19

**Table A-2. Bunk location soil chemistry, texture, and moisture content.**

ID#	Depth m	TC %	TS %	TN %	oC %	TC %	iC %	S %	Si %	C %	crsf	mc ratio
A1-1	0.15	2.18	0.00	0.12							17	0.15
B1-1	0.45	1.45	0.11	0.15							35	0.12
C1-1	0.75	1.25	-0.05	0.10							36	0.11
D1-1	1.1	2.08	-0.05	0.07							23	0.14
E1-1	1.45	1.05	0.00	0.06							14	0.14
F2-1	1.8	0.61	0.06	0.10	0.72	0.79	0.07				1	0.17
G2-1	2.2	6.27	0.11	0.41	6.57	9.14					37	0.12
A4-1	0.15	1.60	-0.11	0.12							28	0.18
B4-1	0.45	1.16	-0.06	0.08							26	0.14
C4-1	0.75	3.22	0.00	0.18							14	0.23
D4-1	1.1	1.42	0.06	0.13							37	0.15
E4-1	1.45	0.91	0.23	0.10							21	0.17
F4-1	1.8	3.11	0.16	0.26							15	0.16
G4-1	2.2	1.53	0.16	0.09	0.88	1.70	0.83	51	45	4	12	0.15
A6-1	0.15	2.61	0.06	0.23	2.19	2.85	0.65				30	
B6-1	0.45	1.52	0.11	0.12	1.35	1.73	0.37				35	0.15
C6-1	0.75	1.60	0.05	0.12	1.12	1.70	0.58				36	0.14
D6-1	1.1	1.54	0.06	0.13	1.16	1.68	0.52				28	0.13
E6-1	1.45	2.23	0.12	0.07	0.55	2.45	1.90				15	0.13
F6-1	1.8	0.79	0.28	0.08	0.75	0.97	0.22	32	60	8	1	0.15
G6-1	2.2	1.54	0.06	0.13							28	0.46
A8-1	0.15	1.98	0.12	0.14	1.42	2.11	0.70	60	36	4	42	0.22
B8-1	0.45	1.57	-0.05	0.13	1.49	1.93	0.44	65	31	4	30	0.17
C8-1	0.75	1.19	0.11	0.12	1.28	1.39	0.11	61	35	4	24	0.16
D8-1	1.1	1.38	0.00	0.12	1.19	1.59	0.40	57	39	4	43	0.13
E8-1	1.45	1.33	0.00	0.10	0.94	1.53	0.59	61	36	3	43	0.13
F8-1	1.8	0.42	-0.11	0.06							20	0.14
G8-1	2.2	1.44	0.00	0.11							31	0.20
A9-1	0.15	2.92	0.00	0.18							55	0.32
B9-1	0.45	1.83	0.00	0.12							35	0.17
C9-1	0.75	1.39	0.00	0.12							31	0.14
D9-1	1.1	1.32	-0.06	0.13							33	0.13
E9-1	1.45	2.11	-0.11	0.09							34	0.13
F9-1	1.8	2.56	0.00	0.09							13	0.12
G9-1	2.2	0.77	0.00	0.10							37	0.23

**Table A-3. Corner soluble chemistry.**

location	ID#	Depth m	EC uS/cm	Ca mg/L	Mg mg/L	Na mg/L	SAR ratio	K mg/L	SO4 mg/L	CL mg/L	NO3 mg/L
corner	1A2	0.15	1560	18.2	6.0	41.2	2.1	410.3	60.3	140.9	8.11
corner	1B2	0.45	1640	27.2	2.9	67.8	3.3	451.4	10.8	96.9	0.17
corner	1C2	0.75	1546	6.3	1.9	70.0	6.2	176.1	9.3	173.5	0.24
corner	1D2	1.1	1299	46.1	25.0	165.4	4.9	34.3	4.6	239.2	0.18
corner	1E2	1.45	1267	52.7	27.9	140.4	3.9	5.2	3.6	178.7	0.16
corner	1F2	1.8	1004	66.9	30.7	54.5	1.4	6.1	1.7	49.3	0.14
corner	1G2	2.2	968	69.7	36.6	21.5	0.5	6.6	1.6	113.1	0.14
corner	2A2	0.15	1500	15.2	4.5	41.9	2.4	423.8	39.2	117.8	0.19
corner	2B2	0.45	1944	10.2	2.7	83.3	6.0	534.6	11.9	123.0	0.18
corner	2C2	0.75	1655	12.3	3.1	94.5	6.2	287.1	6.4	131.2	0.15
corner	2D2	1.1	1352	26.6	20.0	139.7	5.0	42.4	4.4	155.3	0.19
corner	2E2	1.45	1252	53.6	30.1	120.1	3.2	8.5	3.2	142.3	0.17
corner	2F2	1.8	1202	81.4	45.0	52.3	1.2	10.5	1.7	107.0	0.18
corner	2G2	2.2	1089	79.5	48.4	20.5	0.4	20.3	2.0	105.5	0.34
corner	3A2	0.15	1372	16.0	4.7	35.7	2.0	375.5	34.5	162.9	0.21
corner	3B2	0.45	1721	64.0	16.4	73.4	2.1	459.5	11.6	127.9	0.17
corner	est	0.75	1666	41.5	16.4	96.4	3.2	294.6	8.0	155.0	0.15
corner	3D2	1.1	1610	18.9	16.4	119.5	4.8	129.8	4.4	182.0	0.14
corner	3E2	1.45	1385	65.7	40.0	138.5	3.3	14.2	3.8	106.9	0.21
corner	3F2	1.8	1364	81.8	42.4	105.0	2.3	13.0	1.9	80.3	0.14
corner	3G2	2.2	1269	96.2	49.7	35.3	0.7	9.6	1.6	152.9	0.14
corner	4A2	0.15	1724	20.5	5.1	38.1	1.9	444.1	10.1	93.5	0.16
corner	4B2	0.45	1595	19.9	4.4	65.8	3.5	454.2	5.4	118.2	0.15
corner	4C2	0.75	1624	22.9	19.4	134.2	5.0	156.4	7.3	92.6	0.15
corner	4D2	1.1	1301	78.8	32.0	141.9	3.4	11.8	6.7	180.1	0.20
corner	4E2	1.45	1317	92.3	45.6	77.1	1.6	7.5	1.4	138.0	0.14
corner	4F2	1.8	1260	92.7	54.0	32.5	0.7	12.5	1.4	211.0	0.14
corner	4G2	2.2	1122	62.9	36.4	11.4	0.3	9.0	1.5	112.7	0.12
corner	est	0.15	1539	17.5	5.1	39.2	2.1	413.4	36.0	128.8	2.17
corner	5B2	0.45	1763	13.2	7.1	85.9	4.7	379.8	11.9	90.0	0.15
corner	5C2	0.75	1596	12.9	10.7	104.4	5.2	266.3	7.9	91.9	0.16
corner	5D2	1.1	1510	14.7	14.8	113.9	5.0	143.0	12.9	229.2	0.16
corner	5E2	1.45	1328	75.8	37.2	106.3	2.5	10.9	2.3	93.9	0.14
corner	5F2	1.8	1382	110.7	51.2	72.0	1.4	6.9	2.1	124.0	0.10
corner	5G2	2.2	1269	124.4	55.6	28.6	0.5	9.1	1.5	183.4	0.14

**Table A-4. Corner location soil chemistry, texture, and moisture content**

ID#	Depth m	TC %	TS %	TN %	oC %	TC %	IC %	S %	Si %	C %	crsf	mc ratio
1A2	0.15	3.62	0.00	0.11	1.31	3.76	2.45				45	0.23
1B2	0.45	3.03	0.12	0.06	0.78	3.31	2.52				7	0.17
1C2	0.75	2.99	0.11	0.07	0.89	3.24	2.35				12	0.18
1D2	1.1	2.78	0.12	0.06	0.56	3.00	2.43				8	0.17
1E2	1.45	2.77	-8.05	0.05	0.56	2.94	2.38				16	0.20
1F2	1.8	2.57	-0.99	0.04	0.47	2.74	2.27				12	0.18
1G2	2.2	2.62	-0.24	0.04	0.49	2.85	2.36				11	0.15
2A2	0.15	3.10	0.00	0.07							7	0.20
2B2	0.45	3.93	0.11	0.07							4	0.23
2C2	0.75	2.82	0.11	0.07							16	0.16
2D2	1.1	2.69	0.11	0.07							8	0.16
2E2	1.45	3.01	-3.19	0.05							11	0.16
2F2	1.8	2.48	-0.65	0.04							10	0.17
2G2	2.2	2.60	-0.12	0.05							11	0.16
3A2	0.15	2.96	0.12	0.07							14	0.20
3B2	0.45	3.12	0.00	0.07							8	0.19
est	0.75	3.51	8.30	0.07							7	0.18
3D2	1.1	3.90	16.60	0.32							6	0.17
3E2	1.45	2.74	-2.05	0.06							12	0.17
3F2	1.8	2.74	-0.45	0.05							9	0.17
3G2	2.2	2.52	-0.30	0.04							18	0.17
4A2	0.15	2.90	0.16	0.06	0.80	3.04	2.24	38	54	8	14	0.17
4B2	0.45	2.62	0.17	0.06	0.88	2.96	2.07	37	56	7	11	0.16
4C2	0.75	2.65	-0.17	0.09	0.68	2.88	2.19	42	51	7	11	0.16
4D2	1.1	3.43	7.29	0.06	0.66	3.24	2.58	42	51	8	17	0.18
4E2	1.45	2.80	-1.52	0.05	0.68	3.00	2.32	61	36	3	8	0.16
4F2	1.8	2.53	-0.33	0.04	0.56	2.70	2.13	21	69	11	7	0.16
4G2	2.2	2.36	-0.11	0.04	0.58	2.67	2.10	39	53	8	11	0.16
est	0.15	3.15	0.07	0.08							20	0.20
5B2	0.45	3.12	0.12	0.08							9	0.21
5C2	0.75	3.27	0.06	0.09							8	0.19
5D2	1.1	3.57	1.79	0.10							20	0.20
5E2	1.45	2.57	-0.99	0.04							13	0.16
5F2	1.8	3.24	-0.25	0.05							13	0.19
5G2	2.2	2.61	-0.30	0.05							11	0.15

**Table A-5. Mound location soluble chemistry.**

location	ID#	Depth m	EC uS/cm	Ca mg/L	Mg mg/L	Na mg/L	SAR ratio	K mg/L	SO4 mg/L	CL mg/L	NO3 mg/L
mound	1A3	0.15	2394	27.4	10.9	82.5	3.4	738.7	54.8	299.0	0.49
mound	1B3	0.45	1033	7.7	2.2	30.6	2.5	233.5	27.7	124.5	0.33
mound	1C3	0.75	732	6.5	4.9	24.7	1.8	62.3	5.3	140.3	0.24
mound	1D3	1.1	890	60.5	26.6	16.4	0.4	17.6	3.1	133.5	0.19
mound	1E3	1.45	776	52.2	20.6	8.0	0.2	10.2	2.0	136.5	0.17
mound	1F3	1.8	624	114.9	11.7	1.8	0.0	3.5	1.6	55.0	0.11
mound	1G3	2.2	557	31.5	15.0	6.0	0.2	6.8	1.7	60.0	0.41
mound	2A3	0.15	2233	24.5	12.8	79.5	3.2	642.9	50.8	184.0	0.37
mound	2B3	0.45	1822	10.6	8.3	63.4	3.5	518.6	94.7	234.9	
mound	2C3	0.75	1005	9.2	4.7	34.2	2.3	125.9	7.0	171.1	0.15
mound	2D3	1.1	875	43.4	21.1	20.9	0.6	29.0	3.3	107.7	0.25
mound	2E3	1.45	927	54.9	22.3	7.6	0.2	13.5	2.5	159.4	0.25
mound	2F3	1.8	686	47.8	19.2	6.2	0.2	8.8	1.7	108.8	0.75
mound	2G3	2.2	561	32.5	13.6	6.6	0.2	8.6	1.7	71.4	0.30
mound	3A3	0.15	3026	19.1	10.7	94.3	4.3	628.4	53.5	433.5	0.33
mound	3B3	0.45	896	8.4	5.6	29.5	1.9	160.4	35.6	78.9	0.18
mound	3C3	0.75	1715	10.7	4.6	94.0	6.0	384.9	5.7	167.7	0.12
mound	3D3	1.1	992	66.5	27.7	21.0	0.5	19.3	3.2	276.4	0.29
mound	3E3	1.45	623	34.4	12.4	4.7	0.2	6.0	2.0	154.6	0.20
mound	3F3	1.8	541	31.7	11.3	6.1	0.2	7.8	2.0	64.4	0.52
mound	3G3	2.2	753	55.8	19.9	7.6	0.2	10.0	2.0	128.5	0.25
mound	4A3	0.15	574	34.1	13.2	6.0	0.2	6.0	2.2	75.2	0.29
mound	4B3	0.45	1440	8.0	5.6	45.8	3.0	262.1	20.1	93.6	0.19
mound	4C3	0.75	843	27.7	13.5	26.7	1.0	35.3	2.7	126.4	0.15
mound	4D3	1.1	912	71.2	28.8	14.0	0.4	17.0	3.2	158.3	0.12
mound	4E3	1.45	796	60.3	20.6	7.7	0.2	11.1	1.9	140.9	0.19
mound	4F3	1.8	673	48.4	17.6	6.6	0.2	11.0	1.7	108.9	0.35
mound	est	2.2	601	36.0	14.8	7.2	0.3	9.6	1.9	77.3	0.33
mound	5A3	0.15	2523	25.1	33.3	66.0	2.0	399.0	39.1	170.8	3.70
mound	5B3	0.45	1784	15.6	9.7	66.9	3.3	433.7	57.8	166.4	0.15
mound	5C3	0.75	1913	23.7	13.5	66.6	2.7	297.5	14.8	330.3	0.28
mound	5D3	1.1	765	33.0	16.3	18.8	0.7	18.8	2.2	186.0	0.16
mound	5E3	1.45	709	47.9	20.3	9.1	0.3	10.5	2.0	129.0	0.55
mound	est	1.8	622	36.1	15.4	8.8	0.3	11.8	2.2	89.1	0.45
mound	5G3	2.2	534	24.2	10.5	8.5	0.4	13.2	2.3	49.2	0.36

**Table A-6. Mound location soil chemistry, texture, and moisture content**

ID#	Depth m	TC %	TS %	TN %	oC %	TC %	iC %	S %	Si %	C %	crsf %	mc ratio
1A3	0.15	1.34	0.00	0.14	1.35	1.48	0.14				22	0.15
1B3	0.45	0.69	0.00	0.06	0.39	0.63	0.25				67	0.10
1C3	0.75	0.67	0.00	0.05	0.30	1.30	1.01				26	0.04
1D3	1.1	2.36	0.16	0.06	0.69	2.62	1.93				9	0.12
1E3	1.45	2.68	0.00	0.04	0.61	2.85	2.24				7	0.15
1F3	1.8	2.39	0.12	0.04	0.40	2.64	2.24				9	0.13
1G3	2.2	2.35	0.05	0.03	0.34	2.72	2.38				9	0.13
2A3	0.15	1.94	0.05	0.18							22	0.26
2B3	0.45	0.68	0.12	0.09							16	0.12
2C3	0.75	0.79	0.00	0.07							64	0.10
2D3	1.1	1.55	0.11	0.06							18	0.07
2E3	1.45	2.65	0.00	0.05							19	0.18
2F3	1.8	2.81	0.00	0.04							12	0.16
2G3	2.2	2.32	0.00	0.03							7	0.13
3A3	0.15	3.17	0.17	0.25	3.31	3.53	0.22	60	38	3	4	0.27
3B3	0.45	0.57	0.00	0.05	0.41	0.78	0.37	85	15	0	50	0.08
3C3	0.75	2.89	0.12	0.06	0.70	3.21	2.50	23	66	11	10	0.07
3D3	1.1	2.43	-0.06	0.06	0.55	2.63	2.08	24	66	10	15	0.12
3E3	1.45	2.70	-0.17	0.04	0.49	3.10	2.61	42	49	9	8	0.15
3F3	1.8	2.58	0.12	0.04	0.59	2.85	2.26	42	50	8	13	0.15
3G3	2.2	2.63	0.06	0.04	0.52	2.87	2.35	40	52	8	13	0.14
4A3	0.15	0.97	-0.06	0.13							7	0.42
4B3	0.45	0.38	-0.06	0.09							20	0.10
4C3	0.75	0.99	0.00	0.04							46	0.06
4D3	1.1	2.27	0.11	0.05							7	0.11
4E3	1.45	2.47	0.00	0.04							6	0.09
4F3	1.8	2.77	0.18	0.04							15	0.15
est	2.2	2.46	0.03	0.04							9	0.13
5A3	0.15	3.86	0.12	0.31							23	0.42
5B3	0.45	1.57	0.19	0.12							17	0.16
5C3	0.75	0.57	0.00	0.15							1	0.18
5D3	1.1	0.79	0.06	0.05							48	0.15
5E3	1.45	2.72	-0.11	0.05							7	0.19
est	1.8	2.64	-0.05	0.05							8	0.16
5G3	2.2	2.55	0.00	0.04							9	0.13

### A3 Photographs



Example soil profile.  
Intervals are cm  
Depth range is 150 cm

Fig. A-3. Composite photograph of soil profile



